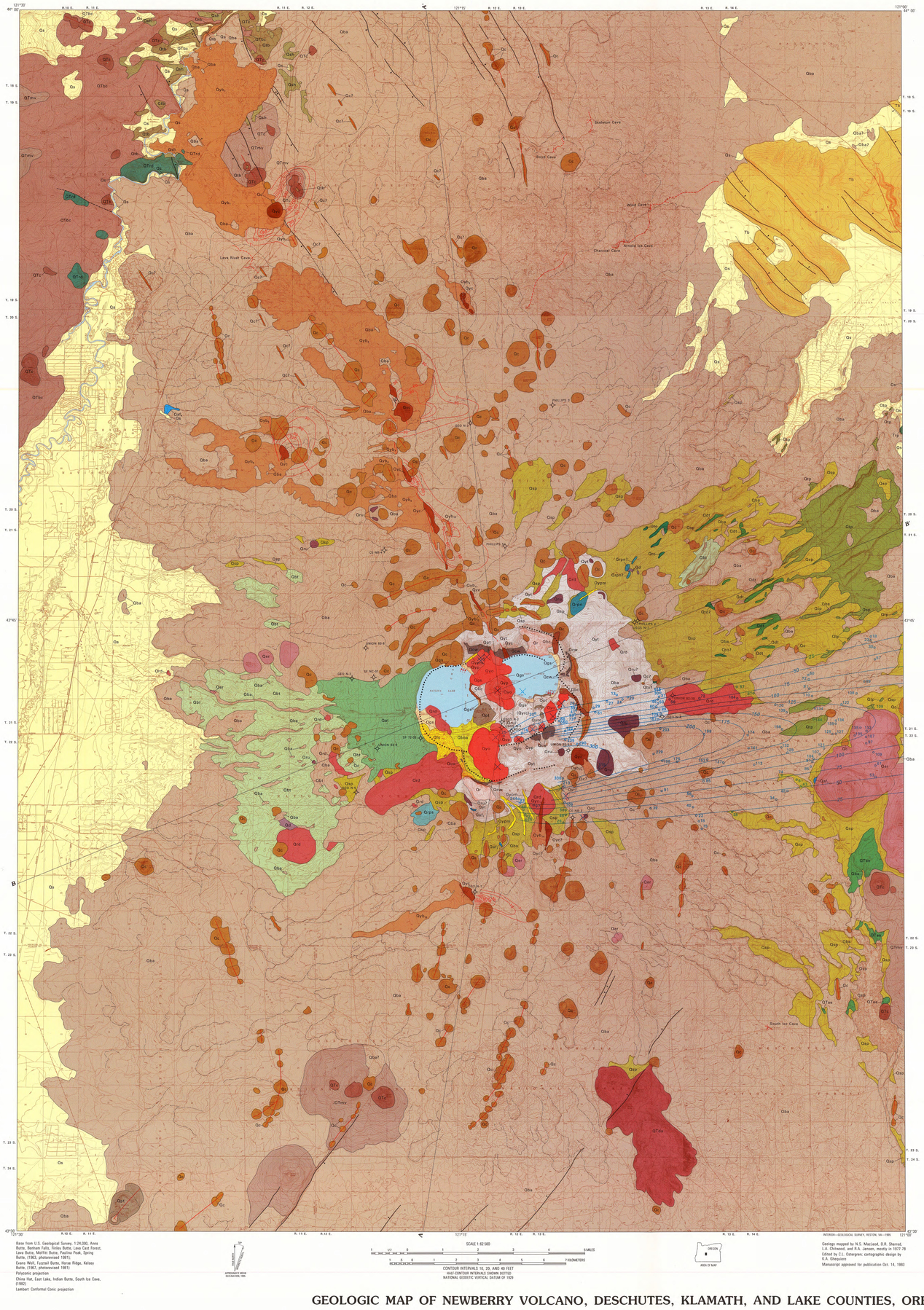
U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS INVESTIGATIONS SERIES
(SHEET 1 OF 2) MAP I–2455
Pamphlet accompanies map



Base from U.S. Geological Survey, 1:24,000, Anns Butte, Benham Falls, Finley Butte, Lava Cast Forest, Lava Butte, Moffitt Butte, Pauline Peak, Spring Butte, (1963, photorevised 1981), Evans Well, Fuzzball Butte, Horse Ridge, Kelsey Butte, (1967, photorevised 1981)

Polyconic projection

China Hat, East Lake, Indian Butte, South Ice Cave, (1982)

Lambert Conformal Conic projection

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1995

Compiled by Norman S. MacLeod, David R. Sherrod, and Lawrence A. Chitwood

Geology mapped by N.S. MacLeod, D.R. Sherrod, L.A. Chitwood, and R.A. Jensen, mostly in 1977–78

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GEOLOGIC MAP OF NEWBERRY VOLCANO, DESCHUTES, KLAMATH, AND LAKE COUNTIES, OREGON

By
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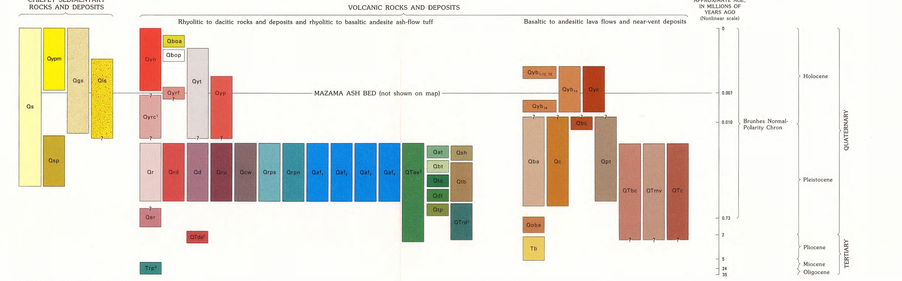
1995

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[Volcanic rocks are named according to chemical classification, in terms of weight percent SiO_2, as follows: basalt, <52 percent; basaltic andesite, ≥52 and <57 percent; andesite, ≥57 and <62 percent; dacite, ≥62 and <67 percent; rhyodacite, ≥67 and <72 percent; rhyolite, ≥72 percent. Rocks without analyses were compared petrographically to analyzed rocks. Representative silica content is reported where available (mainly from Ladley and McKay, 1971; Higgins, 1973; Bayer, 1973; Linneman, 1990; and our own unpublished data) after recalculating the analyses to 100 percent (water-free). Analyses for samples from the caldera are listed in table 5]

[Most basalt and basaltic andesite from Newberry volcano contain phenocrysts of plagioclase, olivine, and locally augite. The more silicic rocks contain plagioclase, hypersthene, and locally augite; hornblende is rare. Quartz and potassium feldspar are absent in essentially all rocks regardless of silica content]

CHIEFLY SEDIMENTARY ROCKS AND DEPOSITS

Qs **Sedimentary deposits (Holocene and Pleistocene)**—Alluvial fan deposits on flank of Newberry volcano that grade outward to interbedded fluvial and lacustrine deposits, especially in Lake Basin. Partly correlative with sedimentary and pyroclastic deposits (Qsp). Unit commonly contains abundant detritus derived from basaltic andesite of Pistachio Flow (Qbap) in northwest part of map area, includes alluvial and glaciofluvial deposits derived from Cascade Range. In and near calderas, consists of reworked lapilli from pumice-fall deposits (Qbop) of the Big Obsidian eruptive period that have washed into closed depressions

Qygm **Young pumiceous mudflow deposits (Holocene)**—Poorly sorted pumiceous ash, lapilli, and blocks that fill floors of ravines. Unit comprises deposits of several ages on upper south and northeast flanks and on north side of caldera near Paulina Lake. Overlies Mazama ash bed

Qgs **Gravel and sand of the caldera (Holocene and Pleistocene)**—Unconsolidated to well-cemented (silicified) pumiceous gravel and sand on southwest and east shores of Paulina Lake and around East Lake. Forms lacustrine terrace deposits several meters higher than present level of Paulina Lake; lake level has been lowered by downcutting of Paulina Creek at outlet of Paulina Lake. These deposits are rich in wood and *Equisetum*. Deposits are mantled by Mazama ash bed and therefore older than about 6,845 ^{14}C yr B.P.; a radiometric age of 4,300±100 ^{14}C yr B.P. (table 1) obtained from wood is too young. Pumiceous gravels at East Lake are older and younger than Mazama ash bed. A post-Mazama level of East Lake 4 m higher than at present is recorded by rounded pumice on wave-cut benches on Interlake Obsidian Flow (unit Qolf, sheet 2). Although not shown, fluvial gravel deposits are found beneath Mazama ash bed and ash-flow deposits (Qboa) southeast of Paulina Lake; they are at a higher elevation than ancestral shoreline deposits and may have been deposited along a former drainage connecting East and Paulina Lakes

Qls **Landslide deposits (Holocene and Pleistocene?)**—Poorly exposed deposits forming hummocky terrain on caldera walls north and east of Paulina Peak. Smaller unmapped landslide and talus deposits are found locally at base of caldera wall, especially on east side of East Lake. Unit mostly older than Mazama ash bed, but includes thin talus deposits that are younger

Qsp **Sedimentary and pyroclastic deposits (Pleistocene)**—Sand, gravel, and angular pumiceous lapilli and ash. Poorly exposed; unit is unindurated or poorly indurated and was mapped on basis of float augmented by reconnaissance excavations. Unit contains abundant cobbles and boulders at higher elevations on flanks of volcano. Locally contains abundant angular lapilli derived from basaltic andesite lapilli tuff (Qbt). Includes rhyolitic pumice-fall deposits exposed on lower east flank; elsewhere, presence of interbedded pumice-fall deposits is suggested by abundant pumice in soil. Overlies all units except Mazama ash bed and rhyolitic pumice deposits (Qb) and is distinguished from it by presence of angular pyroclastic lapilli. Bulk of which is locally so abundant as to suggest that primary pyroclastic deposits are present; similar lapilli in unit Qs are subrounded or well rounded owing to downslope reworking. Age of unit spans several episodes of intermittent erosion and explosive volcanism that occurred during late Pleistocene time

VOLCANIC ROCKS AND DEPOSITS

Rhyolitic to dacitic rocks and deposits and rhyolitic to basaltic andesite ash-flow tuffs

Qyrc **Young obsidian flows of the caldera (Holocene)**—Dense to vesicular or pumiceous, nearly aphyric obsidian lava. Obsidian commonly banded dark gray or black. Surface exposures commonly dense black obsidian or coarsely to finely vesicular pumiceous glass that varies from dark gray to light gray, respectively. Flow surfaces have concentric ridges and furrows; flow fronts are generally steep and as high as 25 m. Vents for flows, shown by "x," are marked by small protrusions that rise above general flow surface. Small craters as much as 60 m across and 15 m deep are scattered over surface of two flows (units Qolf and Qbof, sheet 2). These craters are thought to have formed as result of explosive degassing from flow interior (Jensen, 1993). Flows in the unit are similar in composition; SiO_2 ranges from 72.0 to 74.0 percent. The young obsidian flows, as well as some slightly older rhyolites (Qyrf, Qyrc), differ from most other rhyolitic rocks on Newberry volcano in their much higher B_2O_3 ratio (MacLeod and Sammel, 1982) and by a generally higher content of incompatible trace elements. Younger than Mazama ash bed; hydrazone yield indicates age of about 1,400 to 0.700 yr B.P. (table 2). Unit includes youngest lava flow on Newberry volcano, the Big Obsidian Flow (unit Qbof, sheet 2). Flows are shown as older than Holocene in emptiness period

Qbop **Deposits of the Big Obsidian eruptive period**—On sheet 1 divided into:

Qbop 25 **Ash-flow deposit of Paulina Lake (Holocene)**—Unconsolidated, poorly sorted, pinkish-brown rhyolite pumiceous ash, lapilli, and blocks south of Paulina Lake. Flow of several deposits produced during the Big Obsidian eruptive period as defined on sheet 2; see there for complete description

Qbop **Pumice-fall deposits (Holocene)**—Distribution shown only by isopachs. Well-sorted, angular, light-gray rhyolitic pumice lapilli, less abundant lithic fragments, and minor ash. Contains about 72.8 percent SiO_2 (average of five analyses with little variation). Produced during the Big Obsidian eruptive period. Forms one fall unit on lower east flank; pumice was spalled into a thick fall deposit overlain by several thin fall deposits on upper flank and in caldera. Unit contains breadcrusted accidental lithic fragments derived from vent walls. Age is about 1,500 ^{14}C yr B.P. (table 1). Derived from vent in Big Obsidian Flow (unit Qbof, sheet 2) (Fink and Fink, 1977; Sherrod and MacLeod, 1979) during initial phase of the Big Obsidian eruptive period. Probably only slightly older than ash-flow deposits of Paulina Lake (Qboa), but radiometric age of pumice-fall deposits is about 1,600 ^{14}C yr B.P. (table 1), and therefore unit may be as much as 300 yr older

Qyrf **Young rhyolitic tephra (Holocene and Pleistocene?)**—Thick tephra deposits that completely fill pre-vent areas over caldera and upper flanks. Unit comprises chiefly medial and distal deposits; those near-vent deposits with well-defined physiographic form, such as Central Pumice Cone (unit Qrcp, sheet 2), are mapped separately. Unit contains (1) pumice deposits younger than Mazama ash bed and derived from vents in the caldera, (2) Mazama ash bed, which was derived from caldera-forming eruptions at Crater Lake National Park, and (3) pumice deposits older than Mazama ash bed and probably derived from vents in caldera. As mapped, deposits younger than Mazama ash bed locally include thickest parts of pumiceous fall deposits (Qbop) related to the Big Obsidian eruptive period (distribution shown by isopachs) and East Lake tephra deposit of MacLeod and others (1982). The East Lake tephra deposit, a widespread ash deposit that covers most of east side of caldera and upper east flank of volcano, typically comprises a lower 3-m-thick section of distinctly sorted pumiceous ash, lapilli, and blocks and an upper 1- to 2-m-thick section of bedded pumiceous ash and lapilli with mud-armored pumice lapilli. It probably resulted from phreatomagmatic eruptions at unknown vent(s) in eastern part of caldera, perhaps beneath East Lake as interpreted from bathymetric map (unpublished data; dotted), mean age is 6,400±130 ^{14}C yr B.P. (table 1). Not shown are pre-Mazama pumiceous tephra deposits found at several localities on flanks of volcano. Most are fall deposits of rhyolitic pumice lapilli. These deposits are buried by Mazama ash so their distribution is poorly known. Unit includes the pumiceous tephra deposit of Sherrod and others (1982) that underlies other fall deposits on upper east flank. Age of this deposit is about 7,750±70 radiocarbon years (table 3, No. 31). Overlain by Mazama ash bed and by younger pumice on wave-cut benches on Interlake Obsidian Flow (unit Qolf, sheet 2). Although not shown, fluvial gravel deposits are found beneath Mazama ash bed and ash-flow deposits (Qboa) southeast of Paulina Lake; they are at a higher elevation than ancestral shoreline deposits and may have been deposited along a former drainage connecting East and Paulina Lakes

Qrhp **Rhyodacite pumice deposit of the northeast flank (Pleistocene)**—Unconsolidated to agglutinated pumiceous fall deposits, welded tuff that also may be of fallout origin, and obsidian; the latter may be densely welded tuff, but flowage of material has obliterated macroscopic and microscopic evidence. Phenocrysts of plagioclase, hypersthene, and opaque oxides. Remnant of pumice ring may be indicated by locally well-bedded, steeply dipping deposits of pumiceous blocks, lapilli, and ash. May be equivalent to welded air-fall(?) tuff (part of unit Qpw) that forms uppermost part of the east caldera wall sequence on basis of their chemical similarity and phenocryst content. Unit contains 69.8 percent SiO_2 (one analysis). Queried map-unit symbol indicates area of petrographically similar, weakly agglutinated pumice deposits of probable air-fall origin that underlie pumice-littered hill 5.5 km northeast of East Lake. Potassium-argon age from main exposure 3 km northeast of East Lake is 0.07±0.12 million years (table 3, No. 8)

Ash-flow tuff (Pleistocene)—Four correlated ash-flow tuffs exposed at widely separated localities. Divided into:

Qaf_1 **Tuff southeast of Paulina Peak**—Vitrophyre of either air-fall or ash-flow origin. One exposure, on upper south flank of Newberry volcano, about 2 km southeast of Paulina Peak

Qaf_2 **Lithic-rich pumiceous ash-flow tuff**—One exposure, on upper south flank of Newberry volcano, about 3 km south of Big Obsidian Flow. Well-exposed basal nitrophyre dips 45°–70° northeast. Contact of tuff with surrounding rocks is unexposed, and outcrop may be isolated kipuka older than Newberry volcano

Qaf_3 **Tuff west of China Hat**—Poorly exposed tuff plastered on west side of China Hat *rhyolite dome* (part of unit Qer) near east edge of map area. Slightly porphyritic, with small phenocrysts of plagioclase and sparse iron-rich olivine(?). Contains 71.7 percent SiO_2 (one analysis). Source unknown; may be equivalent to the ash-flow tuff of the lower east flank (Qfae), but exposures are discontinuous and correlation is uncertain

Qaf_4 **Tuff along gas pipeline**—Dark-gray pumiceous welded ash-flow tuff. Contains 65.3 percent SiO_2 (one analysis). Overlain by sedimentary and pyroclastic deposits (Dsp) and mafic lava flows (Qba); contacts with adjacent mafic vent complex (part of unit Qffmv) not exposed. Potassium-argon age of 0.75±0.49 million years (table 3, No. 31), suggesting unit is too old to be a pyroclastic flow of Newberry volcano. However, unit is reversely polarized, which rules out an origin from Newberry volcano and may be equivalent to unit Qaf_2, in which case the K-Ar age is incorrect

Qat **Andesitic tuff (Pleistocene)**—Interbedded porphyritic lapilli and ash that form pyroclastic fall and flow deposits on upper east flank. Phenocrysts are plagioclase, hypersthene, and opaque oxides. Most deposits are moderately to densely welded and very from slightly agglutinated to densely welded; ash-flow deposits are as thick as 3 m, poorly sorted, and weakly consolidated to slightly welded (in basal part). Mostly andesite in composition (four analyses range from 61.1 to 62.8 percent SiO_2), but one sample contains 66.1 percent SiO_2. Unit along caldera rim north of Paulina Creek consists of dense, streaky basaltic andesite lava flows with scattered accidental lithic fragments that probably originated as fountain-fed flows (three analyses, 51.5-52.7 percent SiO_2). Maximum exposed thickness about 30 m. Overlies basaltic andesite lapilli tuff (Qbt) and is banked against and locally overlies cinder-cone deposits (part of unit Qci) and related lava flows on west side of outcrop area; underlies basaltic andesite flows (Qba) on north side. Probably younger than Paulina Peak dome (unit Qrpp, sheet 2), but contact is buried by younger talus deposits. Possesses normal-polarity magnetization; unit has not yielded meaningful K-Ar age (table 3, No. 28). Forms youngest major pyroclastic-flow deposit on volcano

Qbt **Basaltic andesite lapilli tuff (Pleistocene)**—Poorly to moderately consolidated, poorly sorted, dark-gray lapilli tuff. Lapilli and less abundant bombs are finely vesicular to pumiceous, have cauliflower-shaped surfaces, and contain ubiquitous angular rhyolitic to basaltic inclusions; some silicic inclusions are fused and frothed. Matrix is dark ash with abundant accidental lithic fragments. Mostly deposited as pyroclastic flows (fed), as indicated by similar normal magnetic polarity for lapilli and matrix. Mudflow origin may be indicated where unit is palagonitized in largest of three isolated outcrop areas north of McKay Butte on middle west-northwest flank. Maximum exposed thickness about 35 m. Four analyses range from 52.8 to 59.5 percent SiO_2. Unit is deeply eroded, poorly exposed, and has yielded meaningless K-Ar ages (for example, table 3, No. 29). Underlies andesitic tuff (Qat). Overlies some rhyodacite domes and flows (Qrd) that have K-Ar ages of about 0.4 million years (table 3, Nos. 1 and 13). Overlies basaltic andesite flows (Qba) derived from vents middle west flank. Probably younger than Paulina Peak dome (unit Qrpp, sheet 2) on its north and south edges there. Younger than dacitic tuff (Qdt) and overlain by or interbedded with sedimentary and pyroclastic deposits (Dsp) on northeast flank

Qdt **Tuff of Orphan Butte (Pleistocene)**—Dark-gray or brown, very pumiceous ash-flow tuff near Orphan Butte on northeast flank. Crops out sporadically farther south; queried map-unit symbols indicates uncertain assignment for three southernmost exposures of unit. Contains 65.9 percent SiO_2 (one analysis). Interbedded with sedimentary and pyroclastic deposits (Dsp). Younger than dacitic tuff (Qdt); probably older than basaltic andesite lapilli tuff (Qbt). Possesses normal-polarity magnetization. Maximum exposed thickness about 20 m

Qdt **Dacitic tuff (Pleistocene)**—Ash-flow tuff containing dark-gray or brown poorly sorted pumice blocks, lapilli, ash, and minor accidental lithic fragments. Partially welded; pumiceous blocks and lapilli are locally collapsed. Contains ubiquitous obsidian fragments, probably cognate glass. Contains about 66.6 percent SiO_2 (two analyses). Exposed on northeast flank, where it is overlain by or interbedded with sedimentary and pyroclastic deposits (Dsp). Base of unit not exposed. Possesses normal-polarity magnetization. Older than basaltic andesite lapilli tuff (Qbt) and younger than tuff of Tepee Draw (Qtp). Maximum exposed thickness about 20 m

Qtp **Tuff of Tepee Draw (Pleistocene)**—Poorly sorted pumiceous ash, lapilli, and blocks. Moderately porphyritic, containing abundant phenocrysts of plagioclase, subordinate augite and hypersthene, and minor olivine. Unit is densely welded and devitrified in distal exposures; moderately welded upslope from flank of Newberry volcano. Vertical compaction, degree of welding increased within previously welded part exposed at eroded top. Contains about 70.7 percent SiO_2 (two analyses), but differences in pumice color and phenocryst content suggest that unit is compositionally variable. Exposures on lower east and northeast flanks bordered by younger lava flows (Qba) and buried upslope by progressively thicker sedimentary and pyroclastic deposits (Dsp). Locally surrounds kipukas of older basalt (in unit Qba) north of section B-B'. Maximum exposed thickness about 20 m, but base not exposed (except adjacent to kipukas) and upper surface is eroded. Age poorly known; K-Ar ages are 0.50±0.25 and 0.7±0.7 million years (table 3, Nos. 30a and 30b). Possesses normal-polarity magnetization. Older known major pyroclastic unit exposed on volcano

Qsh **Shevlin Park Tuff of Taylor (1993) (Pleistocene)**—Dark-gray andesitic ash-flow tuff, pumice lapilli are andesitic. Contains about 60.4 percent SiO_2 (one analysis, Nimura, 1991). Overlies Tumalo Tuff and Bend Pumice (shown undivided in unit Qtb). Exposures near High Desert Museum (fig. 2 for location) and perhaps elsewhere may, as mapped, include part of Century Drive Tuff of Taylor (1993) (E.M. Taylor and B.E. Hill, oral commun., 1991), which is recognized by its rhyodacitic and andesitic pumice (Hill and Taylor, 1990). Both units erupted from source in Cascade Range northwest of map area

Qtb **Tumalo Tuff and Bend Pumice of Taylor (1981) (Pleistocene)**—Most exposures are weakly consolidated to welded pink rhyolitic ash-flow tuff (Tumalo Tuff). Also includes a locally exposed, *underlying rhyolitic pumiceous air-fall tephra* (Bend Pumice), which is as much as 6 m thick. Exposure at summit of Green Mountain (2.5 km northwest of Lava Butte) contains only of Bend Pumice; exposure at summit of cinder cone 1.5 km northeast of Lava Butte consists of large blocks of Tumalo Tuff. Outcrops of tuff along Deschutes River north of Lava Island (north edge of map area) were assigned by Taylor (1981) to a unit that he named Lava Island Tuff, but that are part of Tumalo Tuff as mapped here. Tumalo Tuff erupted from vent in caldera and has reached by Hill and Taylor (1990). Bend Pumice and Tumalo Tuff are exposed from Lava Butte northward to Bend area, 7 km north of map area. They probably originated as compositionally zonal air-fall deposits from vents spaced approximately 20 km west of Bend (Hill, 1985; Hill and Taylor, 1990). Ten analyses range from 72.5 to 75.5 percent SiO_2 (Nimura, 1991). Tumalo Tuff possesses normal-polarity magnetization. Early geochronologic efforts produced unsatisfactory results; ages ranged from about 4 to 1.8 million years (Fiebelkorn and others, 1983), and several ages were in conflict with known stratigraphic relations. Regional correlations and recently obtained K-Ar ages suggest that the Tumalo Tuff and Bend Pumice are perhaps 0.4-0.3 million years in age (Sarna-Wojcicki and others, 1987, 1989)

Qrtd **Rhyolitic to dacitic domes and flows near Deschutes River (Pleistocene or Pliocene)**—Rhyolite or rhyodacite dome at Benham Falls shows reversed-polarity magnetization and has K-Ar age of 1.8±0.8 million years (table 3, No. 26); overlain by the Tumalo Tuff and Bend Pumice (Qtb). Small, poorly exposed domes or flows southwest of Benham Falls are dacite

Qer **Early rhyolite domes and flows (Pleistocene)**—Aphyric to porphyritic lava with phenocrysts of plagioclase, hypersthene, and variable amounts of augite and iron-rich olivine (as great as 7.0 millim years; that is, older than Brunhes Normal-Polarity Chron, at China Hat (preferred K-Ar age is 0.80±0.21 million years, table 3, No. 24a) and East Butte (K-Ar age is 0.87±0.05 million years, table 3, No. 25) at base of east flank, all possessing reversed-polarity magnetization. (2) three domes of unknown magnetic polarization at and adjacent to McKay Butte on west flank (K-Ar age is 0.60±0.10 million years, table 3, No. 22), and (3) five small domes on southeast flank (ages probably comparable to McKay Butte domes). Unit ranges in composition from 72.8 to 75.0 percent SiO_2 (13 analyses) and is characterized by high B_2O_3 content. Unit includes youngest rhyolitic domes on Pistachio Hill and East Butte domes lie at west end of age-transgressive belt of rhyolitic rocks that extends across eastern Oregon (fig. 1; Walker, 1974; MacLeod and others, 1976). Conceivably all domes in this unit are related to that city-this belt

QTda **Dacite of Amota Butte (Pleistocene or Pliocene)**—Dome complex of Amota and Indian Buttes on lower southeast flank. Seven analyses range from 63.4 to 66.1 percent SiO_2 (Bayer, 1973). Possesses reversed-polarity magnetization, but age is unknown. Older than surrounding mafic lava flows (Qba). Northeast-striking fault that cuts unit has a much higher scarp than in adjacent basaltic andesite (Qba)

Qrp **Rhyolite of Pine Mountain (Miocene or Oligocene)**—Flow or dome in small area along east border of map area near latitude 43°49' N. Unit is more widespread to east where it includes dacite and rhyodacite (Walker and others, 1967); three analyses are 61.2, 72.7, and 72.7 percent SiO_2 (Bayer, 1973). Unit has K-Ar age of 22.0±6 million years (table 3, No. 27, sample location approximately 13 km east of Pine Mountain summit, fig. 2). Age is late Oligocene or early Miocene. Correlative with upper part of John Day Formation

Basaltic to andesitic lava flows and near-vent deposits

Young basaltic vents (Holocene)—Block, aa, and pahoehoe lava flows with sparsely vegetated, youthful surfaces. Lava is fresh, dark gray, aphanitic to sparsely porphyritic, and vesicular. Phenocrysts mostly plagioclase; microphenocrysts of augite and olivine. Unit contains discrete flows numbered 1-15 on map, generally from north to south (see also fig. 4), many of which have formal geographic place names assigned to them (most flows first named by Peterson and Groh, 1965). Erupted from vents marked by young cinder-cone and fissure-vent deposits (Qyci) mainly on northwest flank of Newberry volcano in a zone popularly referred to as northwest rift zone (Peterson and Groh, 1965), although three flows were erupted on south or southeast flanks. Roughly 0.6 km^3 of lava was emplaced along northwest rift zone, mostly in flows erupted at Lava Butte (Qyfs, 0.3 km^3) and Holer Butte (Qyfg, 0.2 km^3). Chemical analyses indicate that most flows are basaltic andesite, but a few are basalt and one may be andesite. Three flows on upper north flank (Qyfa, Qyfb, Qyfc) contain rhyolite and pumice inclusions, probably owing to greater abundance of rhyolitic bedrock (bedrock to the basalt-feeding dikes) toward geographic center of the volcano. Most carbon for dating has been charcoal from tree molds, which yielded ages that are as much as 1,000 years younger than wood from tree molds. Ages 5,800 to 6,400 ^{14}C yr B.P. (table 1), and undated flows are probably of similar age, on basis of preserved surface features. All flows may have been emplaced in a relatively short period of time. Most are known to be younger than Mazama ash bed, but one flow (Qyfba) on southeast flank is older than Mazama ash bed, and another (Qyfcu) is of uncertain age relative to the ash bed, owing to a cover of younger tephra (Qyf). Divided into:

Qyfba **Lava Butte Flow**—On northwest flank of volcano. Seven analyses average 56.3 percent SiO_2 (range is 55.1-57.6 percent SiO_2). Age is 6,160±65 ^{14}C yr B.P. (table 1)

Qyfb **Gas-Line Flows**—On northwest flank of volcano. Unanalyzed. Age determinations are 5,800±150 and 6,150±65 ^{14}C yr B.P. (table 1); weighted mean age is 6,100±60 ^{14}C yr B.P. Unit is older than Lava Butte Flow (Qyfb), but it seems likely that both units are about same age and resulted from northwestward migration of eruptive center

Qyfbu **Mokst Butte Flows**—Northwest flank of volcano. Four analyses average 56.8 percent SiO_2 (range is 56.3-57.8 percent SiO_2). Most lava comprising this unit was previously included in the Mokst Butte Flow of Peterson and Groh (1965). But a flow they named the Twin Vent Flow (Peterson and Groh, 1965), once thought to have erupted from a separate vent, is now known to have erupted from Mokst Butte, and we include it with the Mokst Butte Flows

Flow on middle north flank—Located northeast of Mokst Butte Flows. Unanalyzed

Qyfbs **Flow on west side of Sugarpine Butte**—On northwest flank of volcano. Two analyses: 51.0 and 51.7 percent SiO_2. Age is 5,870±0 ^{14}C yr B.P. (table 1)

Qyfbu **Flow south of Sugarpine Butte**—On northwest flank of volcano. Two analyses: 52.6 and 53.1 percent SiO_2

Qyfc **Forest Road Flow**—On northwest flank of volcano. Two analyses: 52.4 and 53.7 percent SiO_2. Age is 5,960±100 ^{14}C yr B.P. (table 1)

Qyfd **Lava Cast Forest Flow**—On northwest flank of volcano. One analysis: 52.8 percent SiO_2. Age 6,380±130 and 6,150±210 ^{14}C yr B.P. (table 1); weighted mean age is 6,320±110 ^{14}C yr B.P. Name first applied by Peterson and Groh (1965), but locality name "Lava Cast Forest" was in use by U.S. Forest Service prior to 1938 (Nichols and Stearns, 1938)

Qyfe **Lava Cascade Flow**—On northeast flank of volcano. Five analyses range from 53.6 to 55.3 percent SiO_2. Age is 5,800±100 ^{14}C yr B.P. (table 1). Unit overlies Lava Cast Forest Flow (Qyfg) but is underlain by scoria from Lava Cast Forest vent, suggesting that the two flows are about same age

Qyfhs **Flow east of Lava Cascade Flow**—Small flow erupted from fissure 0.8 km east of main fissure system. Known locally as "hidden flow" (Jensen, 1988) because it is mantled by scoria from a west-lying vent that erupted Lava Cascade Flow (Qyfe). Unanalyzed

Qyfu **Flow on upper north flank**—One analysis: 55.0 percent SiO_2

Qyfn **North Summit Flow**—Two analyses: 54.6 and 55.1 percent SiO_2. Age is 6,090±60 ^{14}C yr B.P. (table 1)

Qyfd **The Dome flow**—Informally named flow on upper southeast flank. Erupted from The Dome cinder cone (part of unit Qyci). Overlain by pumice-fall deposits (Qbop) related to the Big Obsidian eruptive period. May predate Mazama ash bed, but none was observed on flow. One analysis: 54.2 percent SiO_2

Qyfh **Devils Horn flow**—Informally named flow on upper south flank. Erupted from Devils Horn cinder vent (part of unit Qyci). Two analyses: 54.3 and 58.0 percent SiO_2. Overlain by pumice-fall deposits (Qbop) related to the Big Obsidian eruptive period. Predates Mazama ash bed

Qyfsv **Surveyor Flow**—On south flank of volcano. Eight analyses average about 54.8 percent SiO_2 (range is 53.1 to 56.1 percent SiO_2). Age determinations are 6,080±100 and 5,835±195 ^{14}C yr B.P. (table 1); weighted mean age is 6,039±90 ^{14}C yr B.P.

Qyci **Young cinder-cone and fissure-vent deposits (Holocene)**—Rudely bedded bombs, blocks, lapilli, ash, and spatter of scoriaceous basaltic andesite, basalt, and minor andesite. Thin cinder-fall deposits extend leeward from most cones and fissures; isopachs shown for cinder-fall deposits associated with Lava Butte, unnamed butte south of Sugarpine Butte, Mokst Butte, vents associated with Forest Road Flow, Lava Cast Forest Flow, and Lava Cascade Flow on northwest flank, and from vent associated with Surveyor Flow (Qyfsv) on south flank. Note that Mokst Butte has two cinder falls, one older than some of its flows and another younger. Some deposits on middle and upper flanks contain inclusions of rhyolite and fused vesicular rhyolitic glass, especially East Lake Fissure (Williams, 1935; Higgins and Waters, 1970). Same age as and related to young basaltic andesite (Qyfs$_{1-14}$), about 6,000 ^{14}C yr B.P. Most deposits are known to be younger than Mazama ash bed, but those associated with Devils Horn flow (Qyfsu) on southeast flank are older, and those associated with The Dome flow (Qyfsu) are of uncertain age relative to Mazama ash bed, owing to a cover of younger tephra (Qyf). Map-unit symbol shown queried for cinder deposits on east side of Devils Horn flow (Qyfsu). These deposits form long ridge (highest point is ragged pinnacle named Devils Horn) and are thought to be younger than Devils Horn flow but may be older and unrelated

Qba **Basaltic andesite (Holocene? and Pleistocene)**—Lava flows typically 0.5 to 3 km long and 10 to 40 m thick. Most are aphyric olivine basalt; some contain olivine and lava tubes are well developed in some flows (Greeley, 1971). Margins of individual flows within unit are shown by dashed lines where readily distinguished; numerous other flow margins are locally obvious but lose expression over short distances and are not shown. Unlabeled except for some older flows on northwestmost and southernmost fields; these flows cover large areas and extend many kilometers beyond map area. Slightly to moderately porphyritic, with phenocrysts of plagioclase, olivine, and locally clinopyroxene. Probably consists chiefly of basaltic andesite, with lesser basalt and minor andesite, on basis of numerous chemical analyses; SiO_2 ranges from 47 to 62 percent (Williams, 1935; Higgins, 1973; Bayer, 1973; Linneman, 1990; our unpub. data). Volumetric proportions of basaltic andesite, basalt, and andesite are poorly known. Analyses are biased towards younger flows, and many voluminous older flows, especially those low on the flanks of the volcano, contain less than 52 percent SiO_2. Older than Mazama ash bed. Youngest part of unit includes flows with well-preserved surface features, which are particularly abundant on southeast, middle southwest, and northwest flanks. These flows may largely postdate last major glacial epoch and thus be younger than about 15,000 yr B.P. Most flows, however, have surfaces covered by pumiceous tephra deposits, fluvial gravel, cinders, and loess or are weathered and older than 15,000 yr B.P. Reconnaissance paleomagnetic determinations suggest that entire unit is normally polarized and likely younger than about 0.73 million years (table 3, Nos. 4, 5, and 6) are considered spurious. Exposures of uncertain assignment are shown by queried map-unit symbol north of Horse Ridge and Green Butte (northeast and southwest corners of map area, respectively)

Qci **Cinder-cone and fissure-vent deposits (Holocene? and Pleistocene)**—Ash, lapilli, blocks, bombs, and agglutinated scoriaceous spatter that form vent deposits related to basaltic andesite, basalt, andesite, and locally dacite of unit Qba. Cinder cones range in size from a few tens of meters to 140 m high and from 100 m to 1 km across; a few are probably small lava shields (Macdonald and others, 1983) or the cone in secs. 8-9, T. 19 S., R. 13 E. Unit includes small, lourdan-fed flows locally associated with mafic vents near north caldera rim. Many deposits contain inclusions of pumice, fused rhyolite, and mafic rocks, which probably were torn from underlying bedrock units. A well-known example is "Mixture Butte" 3 km west-southwest of the caldera in the northeast corner of sec. 5, T. 22 S., R. 12 E. Most cones are monogenetic, but multiple episodes of eruption from some cones are interpreted to be fed by fissures (shown by barred lines on map). Most cone alignments on south flank trend north-northwest, whereas those on north flank trend northwest. Cone alignments on upper north flank commonly are concentric with caldera rim. Queried map-unit symbol indicates areas lacking outcrops but characterized by abundant scoria (float). Age is primarily Pleistocene, but a few deposits could be Holocene

QTsc **Basaltic andesite of the caldera (Holocene?)**—Three lava flows, all of which are overlain by Mazama ash bed and young rhyolitic tephra (Qyrf). Subdivided according to location and probable vent source on sheet 2

Qpt **Palagonite tuff (Holocene? and Pleistocene)**—Palagonitized, formerly glassy basaltic lapilli tuff. Forms (1) tuff cones and rings in caldera at southeast side of Paulina Lake (Little Crater, sheet 2) and on south side of East Lake, each representing eruptions from multiple vents (multiple overlapping crater rim). Unit south of East Lake is probably a vent complex, most of which is buried by young rhyolite tephra (Qyrf). (2) palagonite tuff erupted from an unknown vent and now found glaciated on north caldera wall above Interlake Obsidian Flow (unit Qilf, sheet 2); and (3) tuff cones at Moffitt Butte on southwest flank. The Moffitt Butte cones are older than adjacent lava flows (Qba) and are probably related to a sequence of palagonite tuff cones, rings, and maars extending southwestward beyond map area and including Fort Rock, Hole-in-the-Ground, and Big Hole (fig. 2; Heiken, 1971; Heiken and others, 1981; MacLeod and Sherrod, 1992). Age is chiefly Pleistocene, but full scope of Little Crater may be Holocene

QTsc **Basaltic andesite and basalt flows of the Cascade Range (Pleistocene and Pliocene?)**—Flows exposed west of Deschutes River. Unit includes widespread lava flows of very plagioclase-phyric basalt or basaltic andesite north and west of Benham Falls that were erupted from a large mafic vent complex (part of unit QTmv) near Kiwa Springs (fig. 2), on northwest corner of map area. Some flows are older than Sheelin Park Tuff (Qsh) or Tumalo Tuff and Bend Pumice (shown undivided in Qtb); others are younger

QTmv **Mafic vent complexes (Pleistocene and Pliocene?)**—Shield volcanoes composed of basaltic flows, tuff, and breccia. Most volcanoes are Pleistocene in age, but those on southwest flank of Newberry volcano may be as old as Pliocene

QTc **Cinder-cone deposits (Pleistocene and Pliocene?)**—Vent deposits related to basaltic andesite and basalt flows of the Cascade Range (QTbs). Also includes cinder cones related to mafic vent complexes (QTmv) on northwest, south, and southeast flanks of Newberry volcano

Qoba **Older basaltic andesite (Pleistocene)**—Sampled only in drill holes and shown only in cross section. Lava flows are lithologically similar to those of Pleistocene and Holocene(?) basaltic andesite (Qba) but either possess reversed-polarity magnetization or are known to underlie reversely polarized volcanic rocks. Therefore unit is older than 0.73 million years; that is, older than Brunhes Normal-Polarity Chron. By our interpretation, overlying strata are part of Newberry volcano, whereas this and underlying units may partly or completely predate Newberry volcano

Tb **Basalt (Pliocene and Miocene)**—Unit as shown on geologic map (sheet 1) consists of thin basalt flows, flow breccia, and interbedded near-vent deposits of basaltic cinders, blocks, and bombs that form Horse Ridge in northeast